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SURFACE TREATMENT EFFECTS ON AERMET 100 STEEL: PART 1. SHOT PEENING EFFECT ON CORROSION AND FATIGUE OF AERMET 100 STEEL

by

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12 April 1996

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This study was conducted to identify the effect of shot peening on the corrosion and fatigue behavior of AerMet 100 steel. The specimens were shot-peened with hard cast steel shot, and the induced residual stress profile was determined with the aid of X-ray diffraction. Subsequently, the specimens were undergone to direct tension stress corrosion and immersion corrosion in an aqueous 3.5% NaC1 solution, salt spray corrosion in two separate fog chambers for atomized aqueous 5% NaC1 solution with and without SO_2 gas, and fatigue test in a laboratory environment.

The shot peening induced a residual compressive stress 1,130 MPa at 0.03 mm depth in the specimen. The shot peening did not change the susceptibility of AerMet 100 steel to stress corrosion, but reduced the resistance to immersion corrosion and salt spray corrosion. This unfavorable effect is associated with the surface cold work and greater exposure area generated by the shot peening process. On the other hand, the shot peening extended the fatigue life of AerMet 100 steel.

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STRESS CORROSION	RESIDUAL STRESS
IMMERSION CORROSION	

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ACKNOWLEDGMENT

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The authors acknowledge the assistance of Mr. S. Bettadapur in obtaining funding for this study.

CONTENTS

SUMMARY

This study was initiated to determine the profile of residual stress, induced by shot peening, and to identify the effect of shot peening on stress corrosion, immersion corrosion, salt spray corrosion, and fatigue fracture of AerMet 100 steel.

The residual compressive stress, induced by shot peening, was greater and deeper than that induced by electrodischarge machining (EDM) or polishing. Its maximum magnitude was -1,130 MPa at a depth of 0.03 mm.

Shot peening did not influence the direct tension stress corrosion behavior of AerMet 100 steel. However, it hastened the immersion corrosion by 23 to 100% and the salt spray corrosion by 6 to 25%, depending on the exposure time. This arises from the cold work in the surface layer and the increase in exposure surface area made by shot indentation.

Shot peening resulted in a 100% increase of fatigue life due to the induced residual compressive stress.

It is recommended that the users of AerMet 100 steel be aware of the positive and negative effects of shot peening. To overcome the negative effect, the shot-peened surface of AerMet 100 steel should be protected with corrosion resistant plating.

INTRODUCTION

Shot peening is a cold working process using millions of tiny spheres of steel, glass, or ceramic. These spheres are propelled at about 60 m/sec (200 ft/sec) to a metal component, indent the surface upon impact, induce a residual compressive stress, and cold work the surface layer. The residual compressive stress has been known to improve the fatigue resistance of metallic materials. To take advantage of this benefit, various metal components, such as aircraft landing gear, automobile connecting rod, crank-shaft, spring and gear, are commonly shot-peened.[1,2]

Since its development by Carpenter Technology Corp. in 1990, the use of AerMet 100 steel increased in aircraft and other structural components, including F/A-18E/F aircraft landing gear. However, the effect of shot peening on the properties of AerMet 100 steel, especially the corrosion and fatigue resistance, was not fully understood. Many of Navy aircraft components are exposed to corrosive environments and subjected to repeated loading, and their corrosion and fatigue susceptibility with or without shot peening is a great concern. Therefore, a study was initiated to identify the effect of shot peening on the corrosion and fatigue resistance of AerMet 100 steel. In the corrosion investigation, the susceptibility of shot-peened AerMet 100 steel to stress corrosion, immersion corrosion, and salt spray corrosion was determined. In the fatigue investigation, the fatigue fracture behavior of shot-peened AerMet 100 steel was characterized.

EXPERIMENTAL PROCEDURE

MATERIAL AND SPECIMEN

The specimen material, an AerMet 100 steel forging, was purchased from Carpenter Technology Corp. in the form of a slab, 10 cm (4 in.) wide and 38 mm (1 1/2 in.) thick. Its chemical composition is shown in table 1.

Table 1
CHEMICAL COMPOSITION OF AERMET 100 STEEL

Element	**Weight (%)**
C	0.23
Mn	0.03
Si	0.03
P	0.003
S	0.0009
Cr	3.03
Ni	11.09
Mo	1.18
Co	13.44
Cu	0.01
Fe	bal

This slab was subjected to the following heat treatment: solution treatment at 885°C for 1 hr, oil quenching to room temperature, refrigeration in liquid nitrogen for 1 hr, and aging at 482°C for 5 hr. This heat treatment resulted in the mechanical properties shown in table 2 and the microstructure shown in figure A-1.

Table 2
MECHANICAL PROPERTIES OF AERMET 100 STEEL

Orientation	YS		UTS		K_{IC}	
	MPa	ksi	MPa	ksi	MPa$\sqrt{m}$	ksi$\sqrt{in}$
L-T	1,744.4	253	1,896.1	275	151.7	138
T-L	1,730.6	251	1,916.8	278	146.2	133

Hardness: Rockwell C 52

The specimens were prepared from the slab by EDM, and the specimen surfaces were lightly polished to remove the EDM effect, such as hard and brittle skin created by local surface melting. The selected specimens were rectangular tension test specimens for direct tension stress corrosion tests, square sheet specimens for immersion and salt spray corrosion tests, and round tension test specimens for fatigue tests, figure A-2.

SHOT PEENING

The gage length portions of the rectangular and round tension specimens, and the entire surfaces of the square sheet specimens were shot-peened with MMS-224 hard cast steel shot to an intensity of 0.005 - 0.008 Almen A, following the McDonnell Douglas Aircraft Co. Specification P. S. 14023. The profiles of residual stress in an as-machined specimen, a polished specimen, and a polished and shot-peened specimen were determined with American Stress Technologies X2002 X-ray Diffraction Stress Analyzer.

DIRECT TENSION STRESS CORROSION TEST

The direct tension stress corrosion test was performed with rectangular tension test specimens, as-polished and shot-peened, in a creep test machine at room temperature. The specimen was stressed axially with a dead tensile load. Its gage length portion was enclosed in a plastic container of an aqueous 3.5% NaCl solution. The fracture time was measured for each applied stress, and applied stress versus fracture time was plotted.

IMMERSION AND SALT SPRAY CORROSION TESTS

Prior to environmental exposure, all square sheet specimens, as-polished and shot-peened, were weighed and their dimensions were measured to permit accurate calculation of the exposure area. For the immersion corrosion test, specimens were suspended in an aqueous 3.5% NaCl solution at room temperature. For the salt spray corrosion test, specimens were suspended in a chamber of atomized aqueous 5% NaCl solution fog, and the test was continuous for the entire test period at 95°F. The salt/SO_2 spray corrosion test consisted of continuous salt (aqueous 5% NaCl solution) fog spraying with introduction of SO_2 gas into the chamber twice a day. Specimens were removed from the corrosive environments after each of the preset exposure periods. They were cleaned in a solution of 1,000 ml hydrochloric acid, 20 g antimony trioxide, and 50 g stannous chloride to remove corrosion products, and dried and weighed. The corrosion rate was measured in two ways: (1) reduction in size and (2) reduction in weight per unit time of exposure to a corrosive environment.

FATIGUE TEST

The fatigue tests were performed on a closed-loop servo-hydraulic MTS machine in a laboratory environment at room temperature. The round tension test specimens were subjected to constant amplitude tension-tension loading with a haversine waveform, stress ratio 0.1, and frequency 20 Hz. The fatigue life was defined as the number of loading cycles to fracture and plotted against maximum applied stress.

RESULTS AND DISCUSSION

RESIDUAL STRESS

The profiles of residual stress as they change with depth are shown for the machined, machined and polished, and shot-peened specimens in figure A-3. Within the layer of X-ray diffraction measurement, the residual stress is compressive in all of the three specimens. Its magnitudes are maximum (-874 and -637 MPa) at the surface and decrease with depth in the machined, and machined and polished specimens. However, the magnitude increases initially with depth, reaches the maximum (-1,130 MPa) at a depth of 0.03 mm, and decreases with depth in the shot-peened specimen. The maximum residual compressive stress, -1,130 MPa, is equivalent to 65% of the yield stress of the specimen material. The compressive layer is deepest in the shot-peened specimen, intermediate in the machined specimen, and shallowest in the machined and polished specimen. For example, the layer depths for a compressive stress, -200 MPa, are 0.028, 0.057, and 0.111 mm for the EDM and polishing, EDM, and shot peening, respectively. From this observation, it is evident that shot peening can induce a greater residual compressive stress in a deeper layer than machining or machining and polishing in AerMet 100 steel.

DIRECT TENSION STRESS CORROSION

The time of direct tension stress corrosion fracture is plotted against the applied stress for the as-polished specimens and the shot-peened specimens in figure A-4. The fracture time increases linearly with decreasing stress, and the data points from the two groups of specimens fall on a single straight line. This shows that there is little difference in the stress corrosion fracture time for a given applied stress between the as-polished specimen and the shot-peened one. This also demonstrates that shot peening does not affect the susceptibility of AerMet 100 steel to direct tension stress corrosion in an aqueous 3.5% NaCl solution. On the other hand, it has been reported that the compressive stress from shot peening is effective in retarding and, in many cases, preventing stress corrosion of other alloys.[1,2] Apparently, the compressive stress induced by shot peening in this study is not enough to suppress the direct tension stress corrosion of AerMet 100 steel.

Figures A-5 (a) and (b) show microstructures in the immediate vicinity of a direct tension stress corrosion fracture for an as-polished specimen and a shot-peened specimen, respectively. In both micrographs, a number of secondary cracks are observable, and the fracture and secondary crack paths appear partly intergranular and partly transgranular.

IMMERSION CORROSION

The variation of corrosion rate with immersion exposure time is shown for the as-polished specimens and the shot-peened specimens in figures A-6 (a) and (b). The corrosion rate is greater by 23 to 100%, depending on the exposure time, for the shot-peened specimens than for the as-polished specimens within the exposure time employed. The difference is wider in the initial stage of exposure. The corrosion rate is highest at the beginning of corrosion and decreases

linearly with time throughout the entire exposure period for the as-polished specimens. On the other hand, the corrosion rate is initially very high, decreases rapidly, and then slows down linearly with time in the later stage of corrosion for the shot-peened specimens. This observation suggests that shot peening makes AerMet 100 steel more susceptible to immersion corrosion, particularly in the early stage of exposure. The higher susceptibility of shot-peened specimens to immersion corrosion is attributable to the cold work in the surface layer done and the greater surface exposure area made by shot indentation.

SALT SPRAY CORROSION

The variations of corrosion rate with time of exposure to an atomized aqueous 5% NaCl solution free of and with SO_2 gas are shown for the as-polished specimens and the shot-peened specimens in figures A-7 and A-8. The salt spray corrosion rate is greater by 7 to 14% in the atomized aqueous 5% solution and by 6 to 25% in the atomized aqueous 5% NaCl solution with SO_2 gas for the shot-peened specimens than for the as-polished specimens. It is highest at the beginning of exposure and decreases linearly with exposure time in both of the salt spray environments for the two groups of specimens. Furthermore, the addition of SO_2 gas accelerates the salt spray corrosion, for example, by 10% for 10-day exposure of an as-polished specimen and by 15% for 14-day exposure of a shot-peened specimen.

FATIGUE BEHAVIOR

The fatigue life (number of loading cycles to fracture) is plotted against the maximum applied stress for the as-polished specimens and the shot-peened specimens in figure A-9. The fatigue life of a shot-peened specimen is 100% longer for a given maximum applied stress than that of an as-polished specimen. This result confirms previous observation of fatigue life enhancement by shot peening for the other metallic materials.[1,2]

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CONCLUSIONS

Shot peening induces residual compressive stress of greater magnitude and deeper layer than EDM or polishing can. The maximum magnitude of the induced residual stress is -1,130 MPa, equivalent to 65% of the yield stress of AerMet 100 steel, at a depth of 0.03 mm.

Shot peening does not affect the susceptibility of AerMet 100 steel to direct tension stress corrosion.

Shot peening makes AerMet 100 steel more susceptible to immersion corrosion and salt spray corrosion. It increases the immersion corrosion rate by 23 to 100% and the salt spray corrosion rate by 6 to 25%, depending on the exposure time. This undesirable effect is attributable to the cold work in the surface layer done and the increase in exposure surface area made by shot indentation.

Shot peening extends the fatigue life of AerMet 100 steel by 100% with the induced residual compressive stress.

RECOMMENDATION

Since the shot-peened surface is highly susceptible to corrosion, the users of AerMet 100 steel must be cognizant of the positive and negative aspects of shot peening. One possible solution would be to protect the shot-peened surface with corrosion resistant plating.

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REFERENCES

1. ASM Handbook, Vol. 5, "Surface Engineering," ASM International, Metals Park, OH, 1994, pp. 130-131.

2. Shot Peening Applications, 7th Edition, Metal Improvement Company, Inc., Paramus, N. J.

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APPENDIX A
FIGURES

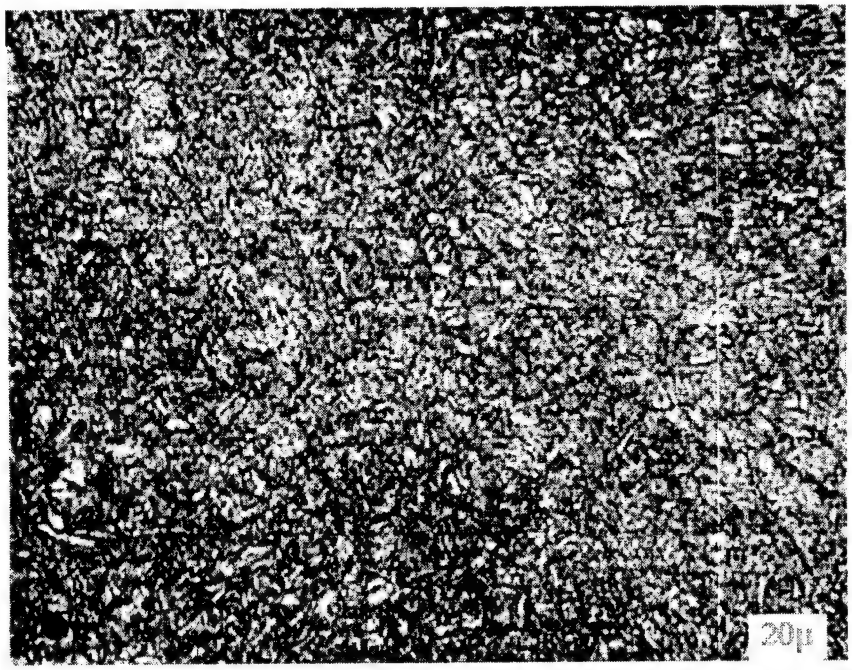


Figure A-1
MICROSTRUCTURE OF SPECIMEN MATERIAL,
AERMET 100 STEEL FORGING

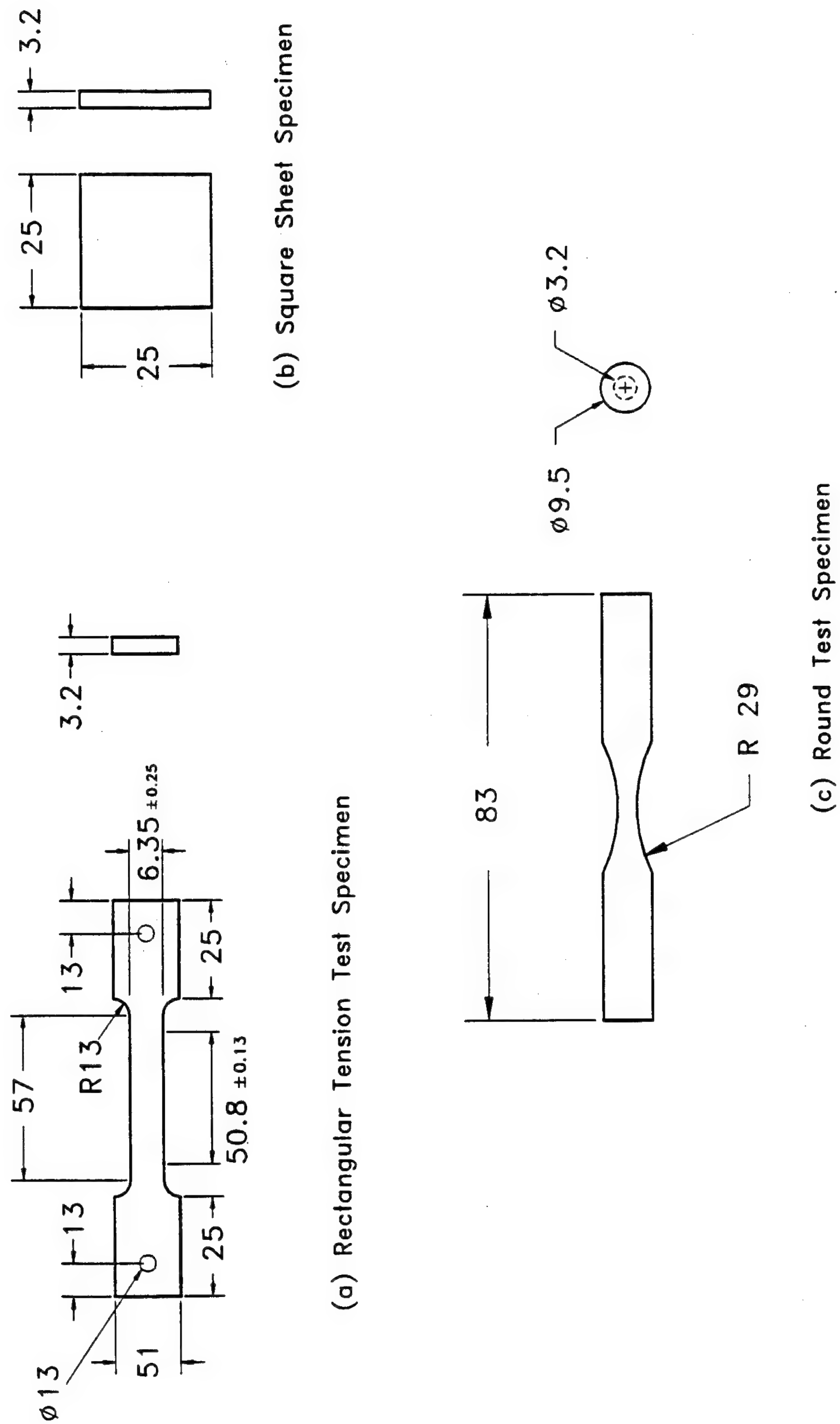


Figure A-2
SPECIMENS

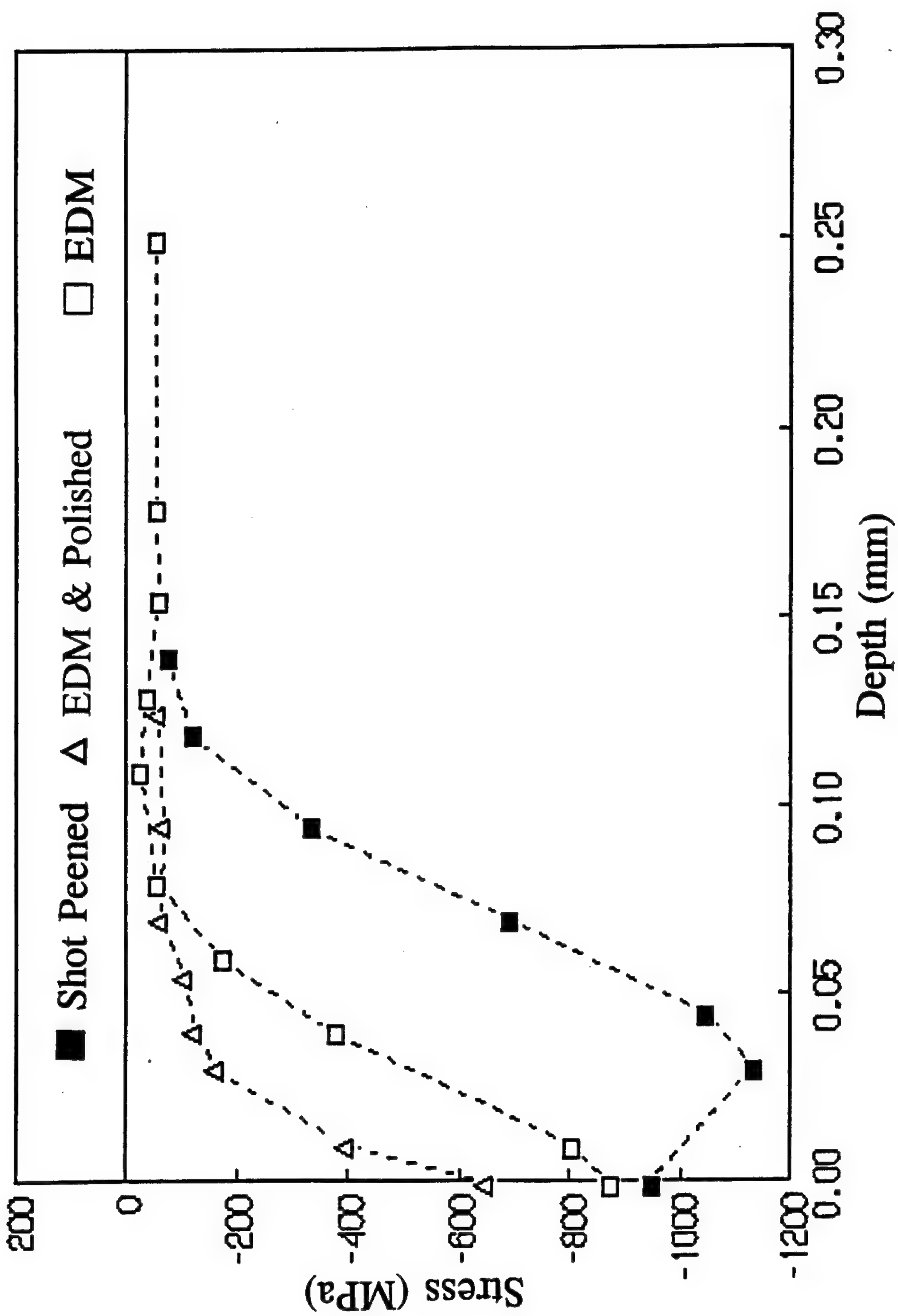


Figure A-3
PROFILE OF RESIDUAL STRESS INDUCED BY SHOT PEENING

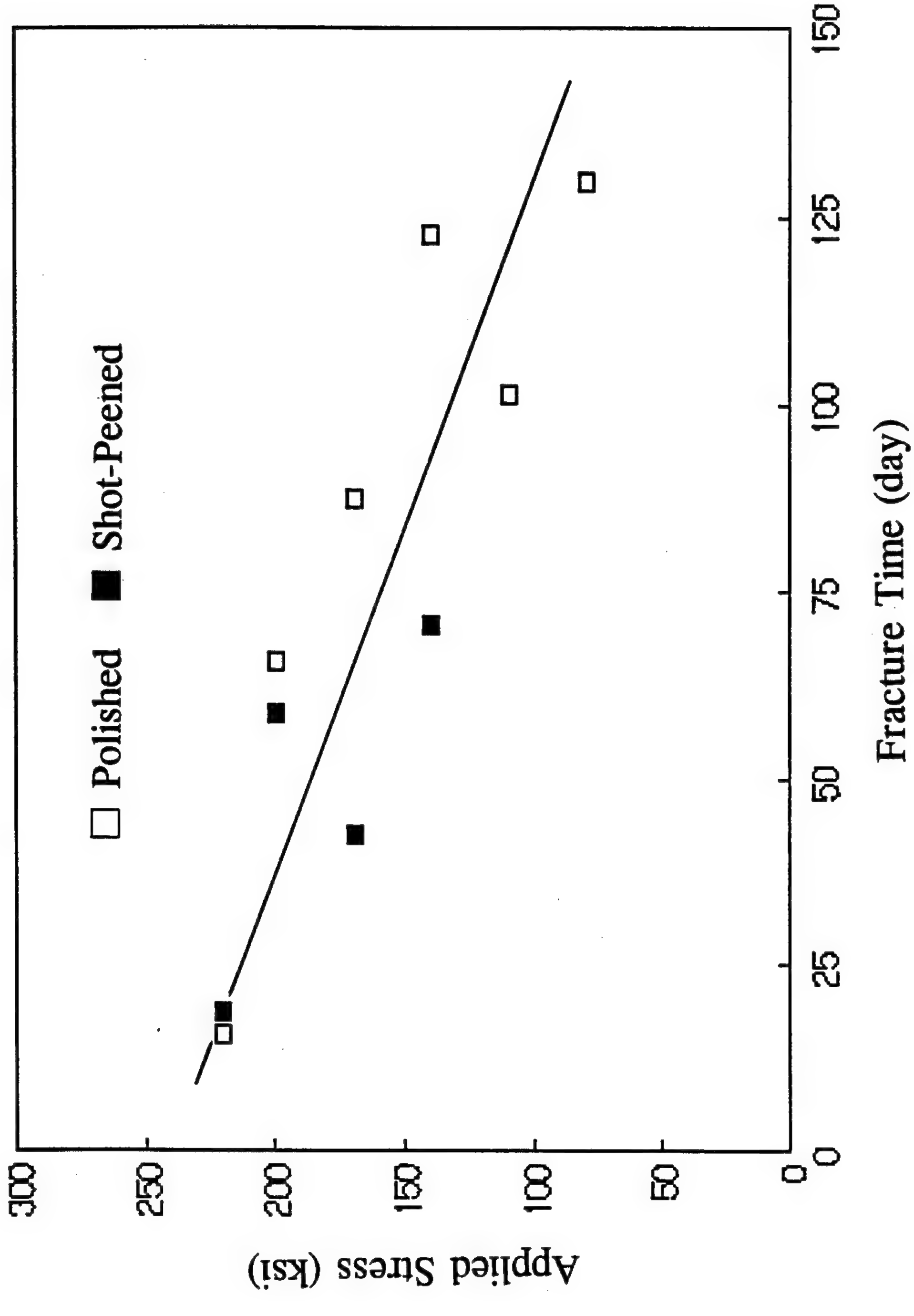
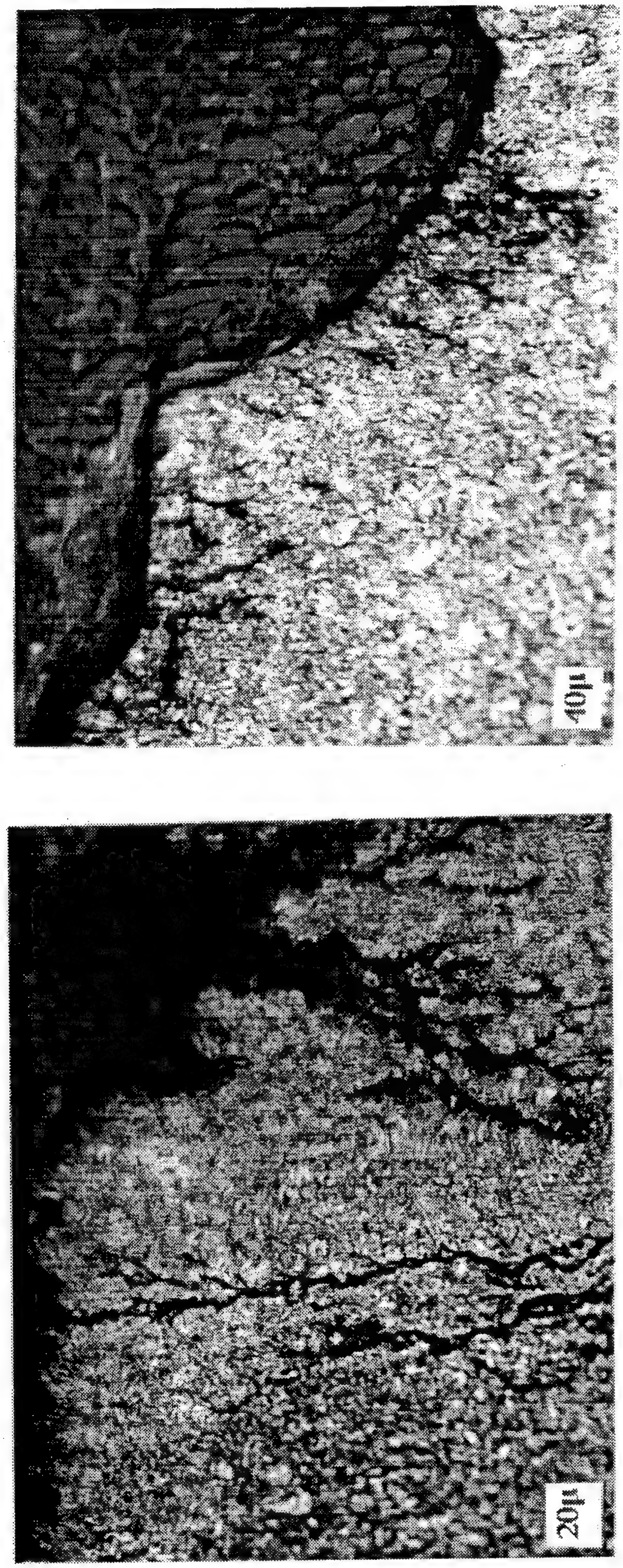


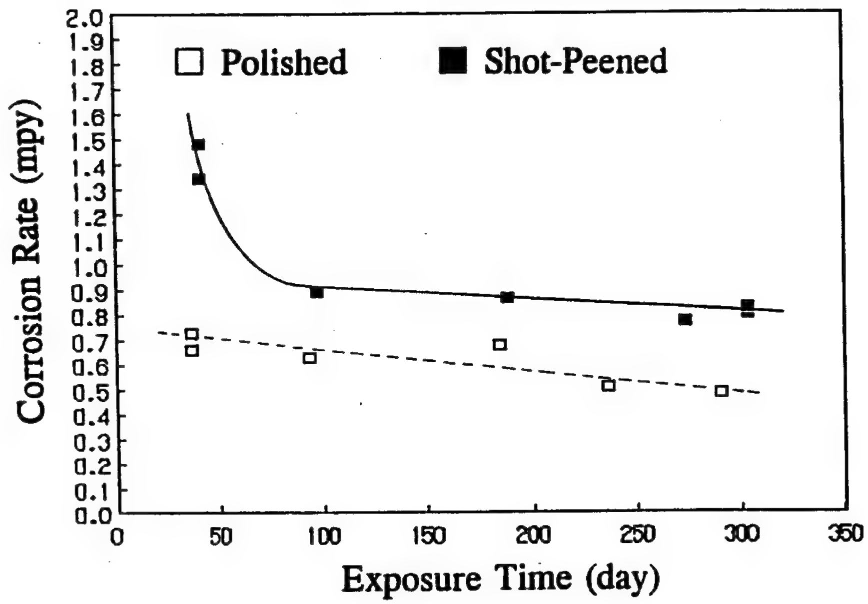
Figure A-4
VARIATION OF SCC FRACTURE TIME WITH APPLIED STRESS IN AQUEOUS 3.5% NaC1 SOLUTION



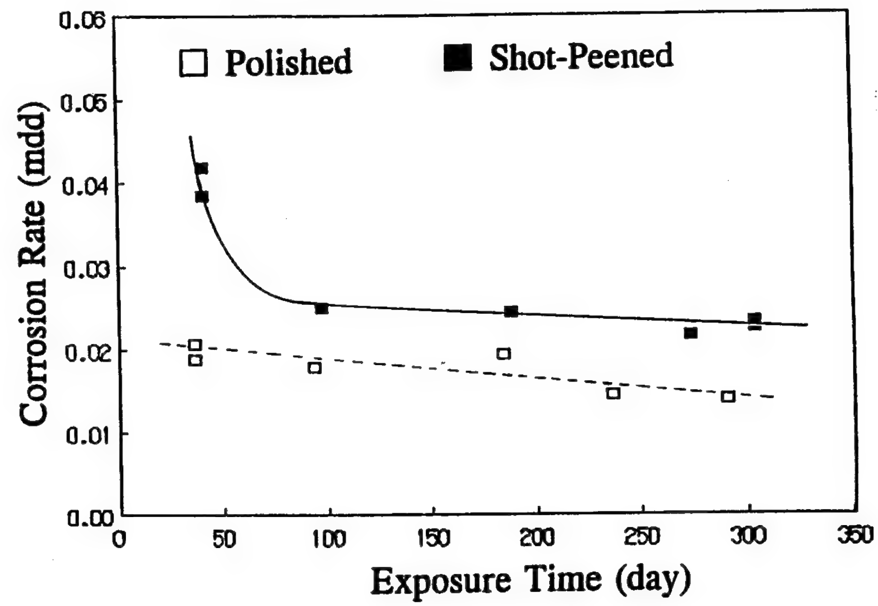
(a) Specimen Surface Polished

(b) Specimen Surface Polished and Shot Peened

Figure A-5
FRACTURE AND CRACK PATH BY DIRECT TENSION STRESS CORROSION IN AQUEOUS 3.5% NaC1 SOLUTION



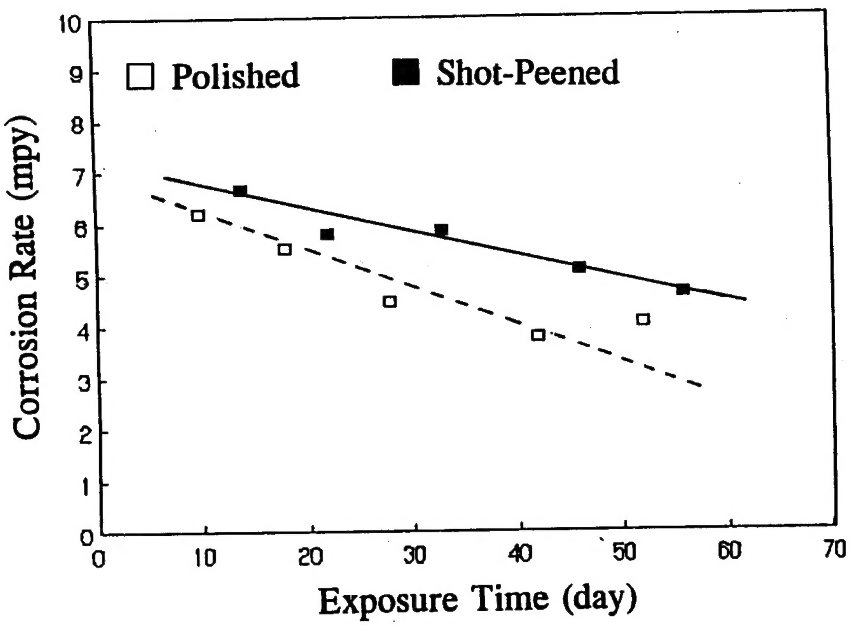
(a) Size Reduction Rate



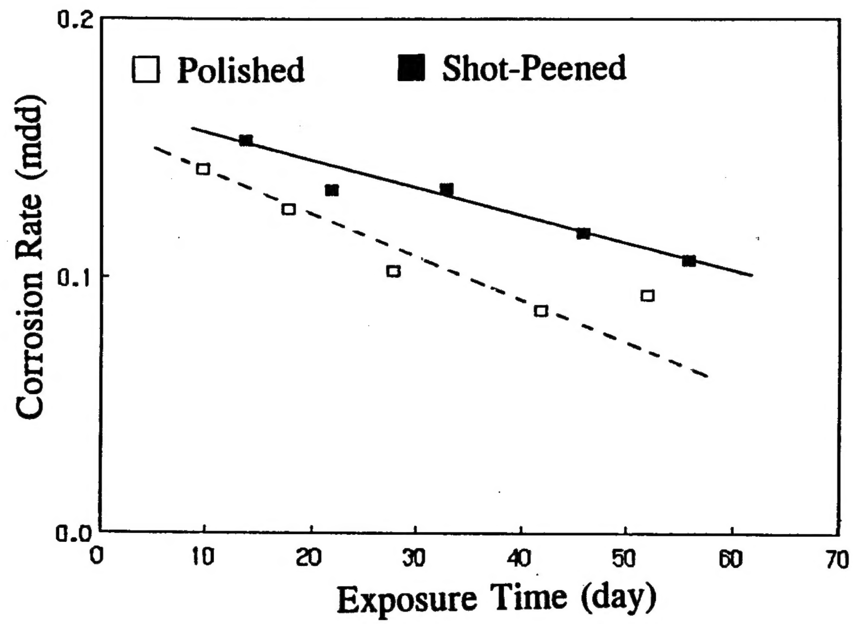
(b) Weight Reduction Rate

(**mpy**: mils per year, **mdd**: milligrams per square decimeter per day)

Figure A-6
VARIATION OF IMMERSION CORROSION RATE WITH EXPOSURE TIME IN AQUEOUS 3.5% NaC1 SOLUTION



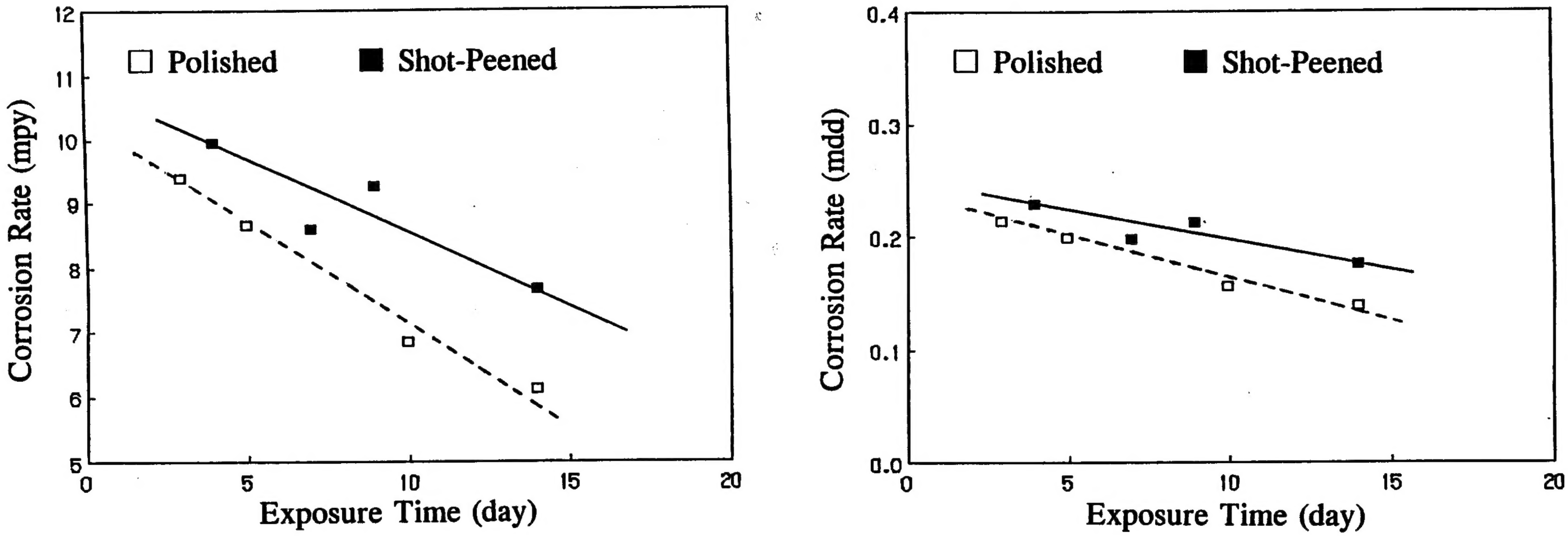
(a) Size Reduction Rate



(b) Weight Reduction Rate

(**mpy**: mils per year, **mdd**: milligrams per square decimeter per day)

Figure A-7
VARIATION OF SALT SPRAY CORROSION RATE WITH EXPOSURE TIME IN AQUEOUS 5% NaC1 SOLUTION FOG



(a) Size Reduction Rate (b) Weight Reduction Rate
(**mpy**: mils per year, **mdd**: milligrams per square decimeter per day)

Figure A-8
VARIATION OF SALT SPRAY CORROSION RATE WITH EXPOSURE TIME IN AQUEOUS 5% NaC1 SOLUTION/SO_2 FOG

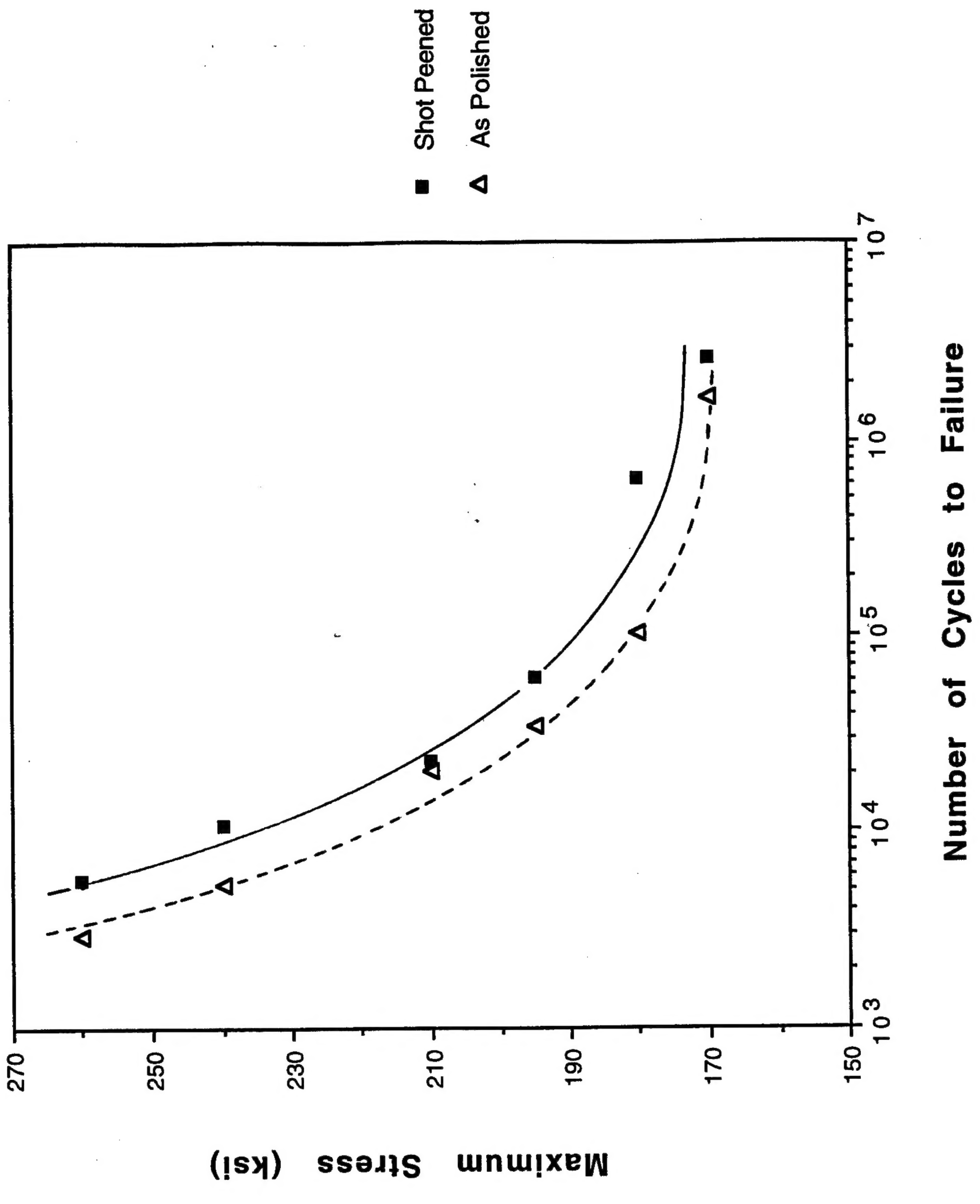


Figure A-9
VARIATION OF FATIGUE LIFE WITH APPLIED MAXIMUM STRESS

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